Imbalance Settlement Exemptions for Offshore Wind Power Generators

Kristof De Vos, *Student Member, IEEE,* Johan Driesen, *Member, IEEE,*
Ronnie Belmans*, Fellow, IEEE*

***Abstract*—This paper evaluates the application of a specific Belgian mechanism to relief offshore wind power generation partially from the imbalance settlement mechanism. A tolerance margin for imbalances originating from offshore production deviations is installed in which producers and balancing responsible parties enjoy beneficial imbalance tariffs.**

This paper investigates background and conditions for this regulation in order to determine if such support mechanisms can be adequate to boost wind power developments.

***Index Terms*—imbalance settlement, offshore wind power, support mechanism, wind power integration**

I. INTRODUCTION: WIND POWER AND IMBALANCE SETTLEMENT

ONE of the main limitation for exploiting large shares of wind power generation is its variability. This power source depends on a variable input resulting in an output characterised by a limited controllability: if no wind is available, no active power can be generated. Furthermore, wind power is not entirely predictable.

Wind energy faces an electricity system which needs an instant balance between demand and supply. Combined with other characteristics as limited storability and variable consumption, this requires a certain control over generation and/or consumption. Question is thus how to balance large amounts of variable generation as wind generation.

To incentivise system balance, most power systems introduced imbalance settlement mechanisms [1]. Therefore, all market players operating in the Belgian electricity market are obliged to have a contract with a balancing responsible party (BRP). This BRP aggregates different market participants and maintains its portfolio in balance by ensuring that injections match off-takes for every 15 minutes. In order for the transmission system operator (TSO) to plan grid operations, these positions have to be sent as nominations to the TSO before gate closure, generally one day in advance.

After this deadline, nominations cannot be altered anymore. However, some tools exist to manage expected imbalances after gate closure due to the availability of new information. These are specifically dealt with in another paper written by the author [2].

When a BRP's portfolio is not in balance at real-time, the BRP has to pay the imbalance tariff for the aggregated imbalances in its portfolio. If the total control zone (aggregation of all BRPs) is not in balance at real time, the TSO, as final responsible for the grid security, activates available reserve capacity in order to restore system balance.

The imbalance settlement mechanism in Belgium is transparently available on the website of the TSO [3] and is represented in Table 1. If a BRP faces a negative imbalance (injections + import + purchase < off-take + export + sales), it is said to be short and is consequently required to buy the missing electricity from the system operator above market price. On the other hand, if the BRPs position is long, it has to sell its surplus to Elia under the market price. These imbalance tariffs are in best case 92% or 108% of the Belpex Day Ahead Market (Belpex DAM) price when the BRP's imbalance counteracts with the system imbalance. In the other case, when the imbalance reinforces the system imbalance, the imbalance tariff is equal or lower than 92% or equal or higher than 108% and introduces an extra uncertain cost (risk) which depends on the volume and cost of the activated regulating reserves.

TABLE 1
IMBALANCE TARIFFS IN THE BELGIAN CONTROL ZONE (SOURCE: ELIA)

	Positive system imbalance	**Negative system imbalance**
Positive imbalance BRP (injection > off-take)	• Max. 0,92 * Belpex DAM • Variable tariff depending on: 1. Downward regulation volume 2. Average downward regulation price 3. Activated downward regulation price	0,92 * Belpex DAM
Negative imbalance BRP (injection < off-take)	1,08 * Belpex DAM	• Min. 1.08 * Belpex DAM • Variable tariff depending on: 1. Upward regulation volume 2. Average upward regulation price 3. Activated upward regulation price

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The authors are with the Department of Electrical Engineering, Katholieke Universiteit Leuven, 3001 Heverlee, Belgium
(e-mail: Kristof.DeVos@esat.kuleuven.be)

This system causes consequently an additional cost for BRPs with wind power in their portfolio. This results from their inability to predict and nominate exactly the injection of wind generation. They have to balance their positions with available flexible generation (portfolio or on the market) or face the imbalance tariff. This is not entirely new to the BRPs as they already gained experience with imbalances caused by load variations and power plant outages. However, experience with variable power sources is still relatively new and prediction tools are improving but still inaccurate. For a single wind power plant day-ahead output forecasts are characterised with a mean absolute error of 20% which may decrease until 5-7% one or two hours before real-time [4].

To tackle these additional imbalance costs resulting from wind power generation, a specific support mechanism is introduced in Belgium to promote the integration of offshore wind power. A tolerance margin for imbalances resulting from this renewable energy source is introduced in which the BRPs enjoy reduced imbalance tariffs.

II. BELGIAN TOLERANCE MARGIN FOR OFFSHORE WIND POWER PRODUCTION

A framework for this tolerance margin was shaped in the Royal Decree of 19 December 2002 (Grid Code). Article 317 introduces the concept for renewable and CHP installations. The specific implementation of this article was however not yet defined. This was done later by the Royal Decree of March 30, 2009, stipulating the execution of such tolerance margin for offshore wind power generation [5],[6]. This regulation came into force June, 3, 2009 and targets specifically deviations of production (difference between the nominated and the measured output, expressed in kW) originating from offshore wind power plants. It is settled per 15 minutes, per individual concession (Art. 2, KB 30/03/2009).

It may be important to clarify the terminology of the "production deviation" used in this legislation. The meaning is explained in Art. 2 and refers to the difference between the nominated and the real-time measured power output. In case of wind power, the nominated output is generally determined by the predictions. It is important to emphasize the difference with the concept of imbalance which refers to the difference between injections and off-takes in a BRP's portfolio: this encompasses the aggregation of all generation and load deviations. Consequently, a production deviation may be the cause of an imbalance in the portfolio but does not necessarily needs to when the production deviation is for instance counteracted by an opposite demand deviation.

The core of this regulation is that for an individual offshore wind power plant, imbalances originating from offshore production deviations (measured minus nominated output) up to 30% of the nominated offshore capacity are to be bought or sold by Elia respectively at 90% or 110% of the reference market price (Belpex DAM). This mechanism is in fact similar to the normal imbalance settlement mechanism, except that now, when the wind farms' production deviation reinforces the overall system imbalance, higher uncertain tariffs can be avoided. The amount of energy which corresponds to a production deviation exceeding the 30% margin is again subject to the normal imbalance settlement tariffs shown in Table 1.

The mechanism is illustrated in Fig. 1 and Table 2: if for an offshore wind power plant, 200 MW is nominated for the first part of the day, all deviations inside 140 MW and 260 MW are settled with Elia at the advantageous tariff (90% / 110% of the Belpex DAM price). A positive imbalance, for instance a real-time production of 280 MW at 7h00, is only for 20 MW subject to the normal imbalance settlement which might be higher than 10% of the market reference price. The first 60 MW however falls within the tolerance margin.

Table 3 and Table 4 built on the previous example by attaching the relevant imbalance tariffs. A situation is assumed where a BRP's imbalance is entirely originating from the production deviation of an offshore wind power plant. This wind power plant faces an electricity price of 40 €/MWh on the Belpex DAM and imbalance tariffs of 20/60 €/MWh when the imbalance reinforces the system imbalance. To simplify the example, a settlement period of one hour is taken instead of 15 minutes.

Comparing a scenario without (Table 3) and with (Table 4) tolerance margin, it can be seen that the regulation is specifically advantageous in situations where the BRP's imbalance reinforces the system imbalance. Otherwise, when counter-acting on the system imbalance, wind power deviations falling under the tolerance margin are paid systematically 2% more in comparison with the normal settlement mechanism. Although the tolerance margin puts the wind power producer in disadvantage in these situations, this is largely compensated by the tariff reductions in the other case.

To ensure grid stability, such support mechanism cannot be allowed to harm the incentive of the generator to minimise imbalances and to nominate wind generation according to the best predictions available. This is assured in the regulation with a few specific articles:

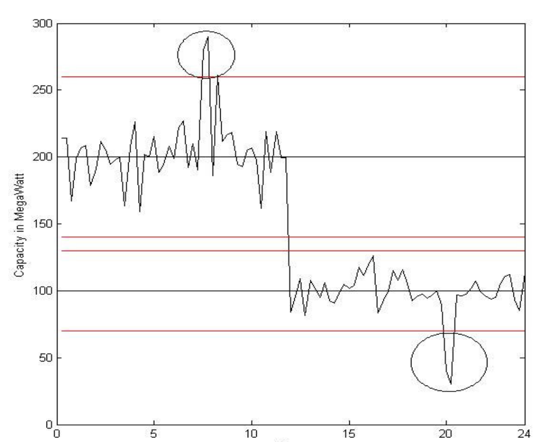

Fig. 1 Tolerance margin of 30% for offshore nomination of 200 MW (0h00-12h00) and 100 MW (12h00-24h00)

TABLE 2
IMBALANCE TARIFFS IN THE BELGIAN CONTROL ZONE (SOURCE: ELIA)

	≤ 30 %	> 30 %	
		Negative system imbalance	**Positive System Imbalance**
Positive imbalance BRP	0,90 * Belpex DAM	0,92 * Belpex DAM	≤ 0,92 * Belpex DAM
Negative imbalance BRP	1,10 * Belpex DAM	≥ 1,08 * Belpex DAM	1,08 * Belpex DAM

TABLE 3
IMBALANCE COSTS FOR A WIND FARM WITHOUT 30% TOLERANCE MARGIN

	Positive system imbalance	Negative system Imbalance
Positive imbalance BRP (80 MW)	80 MW * €20 = €1600	80 MW * 92% * 40€ = €2944
Negative imbalance BRP (80 MW)	80 MW * 108% * -40€ = €-3456	80 MW * €-60 = €-4800

TABLE 4
IMBALANCE COSTS FOR A WIND FARM WITH 30% TOLERANCE MARGIN

	Positive system imbalance	Negative system Imbalance
Positive imbalance BRP (80 MW)	60 MW * 90% * €40 + 20 MW * €20 = €2560	60 MW * 90% * €40 + 20 MW * 92% * €40 = €2896
Negative imbalance BRP (80 MW)	60 MW * 110% * €-40 + 20 MW * 108% * €-20 = €-3504	60 MW * 110% * €-40 + 20 MW * €-60 = €-3840

-- The best forecasting tools available at reasonable price must be applied (Art. 4) after which the most accurate forecasts have to be nominated (Art. 2). Results and methods for forecasting must be extensively communicated with the grid operator (Art. 4).

-- The transmission system operator respectively buys or sells the surplus or shortage of electrical energy caused by the imbalance at the Belpex reference market price (Art. 6) decreased or increased with 10%. This means that the generator is still penalised for its imbalance and the incentive to minimise is maintained.

-- If the Intra-day Production mechanism is applied, the adapted nomination is used as a reference to calculate the deviation (Art. 3). The intra-day production mechanism (in place from 2009) allows a generator to change its nomination intra-day provided that the system operator approves this change. The new nomination has to be between the value of the last nomination and the prediction at the moment of submitting the intra-day nomination.

These conditions give the generators the incentive to apply the best forecasting tools available and reduce its imbalance volumes. This support mechanism is merely designed to create a financial compensation without worsening the impact on grid security.

A few critical remarks concerning this mechanism are however to be made: first the advantageous tariffs are not consistent with the tariffs of the imbalance settlement. When this regulation was designed the minimum tariffs of the imbalance settlement mechanism were 90% or 110% of the market reference price. A few years ago, the general imbalance tariffs were adapted to 92% and 108% which is not altered in the tolerance margin mechanism. This means that this support mechanism leads to a systematic disadvantage of 2% in times when the offshore wind farm imbalance counteracts with the system imbalance.

A second remark is that the contractual structure of this regulation is rather complex (Fig. 2). The imbalance settlement mechanism is generally a relation between the BRP and the TSO as described in the previous section. This relation is largely maintained when applying the 30%-exemption rule (Art. 5). The BRP nominates and balances its position and is accountable for the aggregated imbalance of its portfolio. However, offshore production deviations under 30% of the nomination are bought or sold by the TSO from the concessionaire (Art. 6). This results in a contractual relation between the TSO and the wind farm concessionaire. The reference, the nomination is again delivered by the BRP (day-ahead, intra-day). These nominations submitted by the BRP are binding for the wind park concessionaire (Art. 7).
The complexity of this relationship is that now, the BRP as well as the wind park developer become accountable for their deviations. Normally, only the BRP bears this responsibility as this party nominates the expected production of the wind park. In the current situation, also the wind park developer has to however contractually agree with the grid operator and the BRP to transfer all rights and duties concerning to this rule to its BRP (Art. 7).

A similar tolerance margin was installed in Spain with the second regulation (Spanish Royal Decree 436/2004). All wind power plants larger than 10 MW applying the feed-in tariff were obliged to predict the power output for every 60 minutes before 18h00 D-2. The absolute error between prediction and production was subject to an imbalance tariff when exceeding a tolerance margin of 20% [7]. This support mechanism disappeared in the third regulation (Royal Decree 661/2007). Wind power imbalances are today treated in the same way as under the feed-in premium system, it is namely fully responsible for its imbalances.

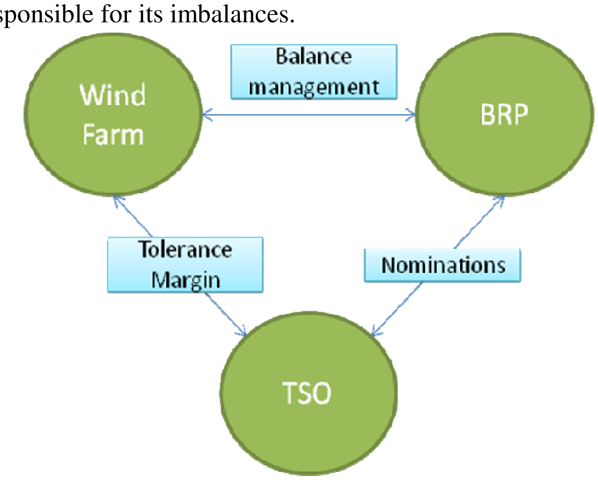

Fig. 2 Contractual representation of the 30% tolerance margin

III. PREDICTABILITY OF WIND RESOURCES AT OFFSHORE LOCATIONS

In this section, the underlying motivation of the 30%-mechanism is researched, namely the presumed higher unpredictability of wind resources at offshore locations. This assumption is often used as an argument by the advocates of the mechanism. However, if this larger variability would be disproved, the specific support mechanism becomes nothing more than a subsidy to boost offshore wind generation. In this case, other, more transparent support schemes could be considered.

In order to address this research target, a preliminary analysis was performed for the Nord Sea area. Prediction errors from five locations in the Netherlands are studied: two offshore ones (Vlakte Van De Raan and Lichteiland Goeree) are compared with three onshore (Eindhoven, Woensdrecht and Stavenisse) (Fig. 3). As these locations are situated in the same climate zone, these wind speeds can be assumed representative for Belgium.

Hourly measured wind speeds for these locations are obtained from the Royal Dutch Meteorological Institute [8]. Statistical parameters describing wind speed characteristics at 100 m altitude are shown in Table 5. It can be concluded that offshore wind locations are characterised by a higher average wind speed and standard deviation.

Measured wind speeds must be compared with the predicted to calculate the prediction error in m/s. Forecast data is acquired from ECN (Energieonderzoek Centrum Nederland) which is used to perform day-ahead predictions (delivered each day around 14h00 for the next 72 hours, 10-minute resolution) [9]. When evaluating the prediction error expressed in MW, different parameters may be utilised. In literature, three common error measures are used [10] to evaluate prediction errors expressed in m/s (predicted wind speed – measured wind speed):

-- Average error over the evaluation period (BIAS):

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(X_{predicted,i} - X_{measured,i})$$

-- Mean Absolute Error (MAE):

$$MAE = \frac{1}{N}\sum_{i=1}^{N}| X_{predicted,i} - X_{measured,i} |$$

-- Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_{predicted,i} - X_{measured,i})^2}$$

Table 6 shows these statistical parameters of the wind speed prediction error expressed in m/s. For the five locations, the statistical indicators are always larger for the offshore locations than the onshore. Therefore, it may already be concluded that offshore wind speeds seem to be indeed less predictable.

Fig. 3 Geographical representation of the three locations of measurement

TABLE 5
STATISTICAL PARAMETERS OF THE MEASURED WIND SPEEDS AT 100 METERS HEIGHT (2004)

[m./sec.]	DE RAAN	GOEREE	STAVENISSE	WOENSDR.	EINDHOVEN
Mean	9,18	9,41	7,50	5,78	5,90
St.dev.	4,67	4,85	4,07	3,65	3,43
Max.	28,20	28,84	28,58	25,00	23,88

TABLE 6
STATISTICAL PARAMETERS OF THE WIND SPEED PREDICTION ERROR

[m./sec.]	DE RAAN	GOEREE	STAVENISSE	WOENSDR.	EINDHOVEN
BIAS	-0,74	-0,87	0,16	0,57	0,65
MAE	2,10	2,01	1,77	1,89	1,81
RMSE	2,70	2,60	2,29	2,35	2,26

IV. IMBALANCES ORIGINATING FROM THE PRODUCTION DEVIATIONS OF AN OFFSHORE WIND POWER PLANT

The production deviation of a single wind power plant is calculated by subtracting the nominated (day-ahead, intra-day) from the measured active power output. Nominations are generally based on wind speed predictions and the measured output is normally in function of the measured wind speed. In this case-study, the BRP's imbalance is assumed equal to the production deviation. This means that the portfolio or intra-day balancing possibilities are not taken into account.

In order to transform the wind speeds to active power, a power curve is used which represents the output characteristics of a wind turbine, farm or park. For this study, normalised, regional aggregated power curves from the TradeWind project are used representing current technology [11]. When evaluating the output of a farm or park, these curves are more realistic than the use of individual power curves as they take into account wind park effects (wake, electrical losses, unavailability). This result in smoother curves (not all turbines start generating power at the same time), lower active power output (aerodynamical and electrical losses, unavailability,...) and a smooth decrease in power output in case of high wind speeds (not all wind turbines shut down at the same time during a storm). This is shown in Fig. 3.

When production deviations are calculated as the predicted minus the measured output, a negative prediction error means that the wind speed was underestimated leading to a positive imbalance. The BRP is long and needs to balance its position or to sell the imbalanced volume to the system operator below market price. A negative imbalance means the BRP is short and has to buy reserves from the system operator.

Results may be evaluated with the same statistical parameters as in Table 6. However, in order to make results independent from the wind farm or park size, the normalised error measures can be used by dividing the imbalances by the installed capacity. When evaluating the results shown in Table 7, the main conclusion is that the higher unpredictability offshore can be confirmed when looking at the absolute production deviations. A second remark is that the BIAS-indicator reveals systematic underestimations offshore and overestimations onshore. When looking at the probabilistic distribution of the absolute imbalance error in Fig. 4, it can be seen that small imbalances (< 20%) occur more in the onshore locations while larger imbalances occur more in the offshore locations.

With these results it is not possible to reject the assumption of higher unpredictability and consequently higher imbalance volumes and costs offshore. However it is important to keep in mind that the difference is not that large and that the study is performed on a small population of five locations. Second, one can argue that offshore prediction tools are relatively new and more improvement in accuracy is expected in comparison with the more mature onshore prediction tools.

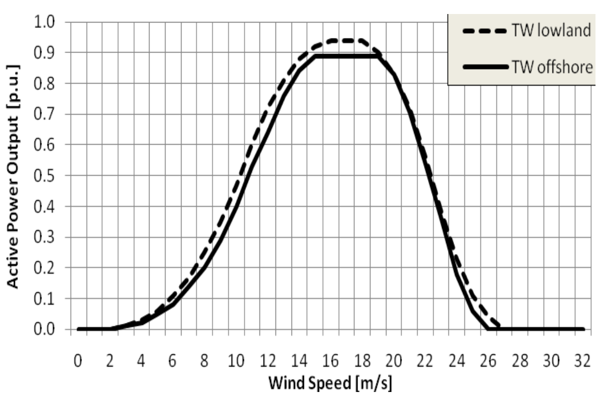

FIG. 3 REGIONAL NORMALISED POWER CURVES (SOURCE: TRADEWIND)

TABLE 7
NORMALISED STATISTICAL PARAMETERS CONCERNING IMBALANCE OF AN OFFSHORE WIND POWER PLANT

[%]	DE RAAN	GOEREE	STAVENISSE	WOENSDR.	EINDHOVEN
NBIAS	-5,05	-5,53	1,41	1,11	2,75
NMAE	13,07	12,28	10,76	8,54	8,97
NRMSE	19,39	18,53	16,66	13,13	13,95
NMAX	79,26	89,00	78,96	66,32	80,39

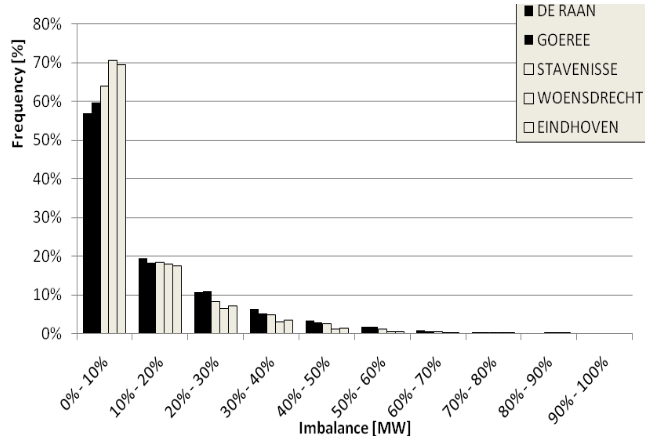

FIG. 4 PROBABILITY FUNCTION OF NORMALISED IMBALANCES

V. CONCLUSIONS

The aim of this paper is to review the specific Belgian support mechanism to reduce imbalance costs for offshore wind power. This mechanism allow offshore generators to enjoy beneficial imbalance tariffs when deviations stay inside a 30% tolerance margin. This is defended by the higher unpredictability of active power output offshore.

A preliminary study with five offshore and onshore locations confirms this argumentation with prediction errors (RMSE) being 2-6% higher for offshore locations. Consequently, this increases imbalance costs and could indeed discourage wind park developers to invest in offshore locations.

Although this support mechanism can be defended as it directly tackles the imbalance cost, this regulation is anything but transparent. The complexity of the execution of this regulation raises the question if this support mechanism for offshore wind generation could not be replaced by other easier, more transparent support mechanisms. The same support effect could for instance be achieved by increasing the minimal price of the green certificates received for offshore wind power.

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